

Sedentary patterns and cardiometabolic risk

Title: Associations between prolonged sedentary time and breaks in sedentary time with cardiometabolic risk in 10-14 year-old children: the HAPPY study

*Daniel P Bailey^a, Sarah J Charman^b, Thomas Ploetz^c, Louise A Savory^a, Catherine J Kerr^d.

^aInstitute for Sport and Physical Activity Research, School of Sport Science and Physical Activity, University of Bedfordshire, Polhill Avenue, Bedford, United Kingdom.

^bInstitute of Cellular Medicine, Newcastle University, Newcastle upon Tyne, United Kingdom.

^cOpen Lab, School of Computing Science, Newcastle University, Newcastle upon Tyne, United Kingdom.

^dAllied & Public Health, Faculty of Medical Science, Anglia Ruskin University, East Road Campus, Young Street Site, Cambridge.

***Corresponding author:** Dr. Daniel Bailey, Institute for Sport and Physical Activity Research, School of Sport Science and Physical Activity, University of Bedfordshire, Polhill Avenue, Bedford, Bedfordshire, MK41 9EA, UK. Phone: +441234 793237, email: daniel.bailey@beds.ac.uk.

Abstract word count: 174

Main text word count: 4,441

Running Title: Sedentary patterns and cardiometabolic risk

Keywords: Sedentary bout; sedentary time; physical activity; cardiometabolic risk; cardiorespiratory fitness

1 **Abstract**

2 This study examines the association between prolonged sedentary time and breaks
3 in sedentary time with cardiometabolic risk in 10-14 year-old children. This cross-
4 sectional design study analysed accelerometry-determined sedentary behaviour
5 and physical activity collected over seven days from 111 (66 girls) UK
6 schoolchildren. Objective outcome measures included waist circumference, fasting
7 lipids, fasting glucose, blood pressure, and cardiorespiratory fitness. Logistic
8 regression was used for the main data analysis. After adjustment for confounders,
9 the odds of having hypertriglyceridaemia ($p=0.03$) and an increased clustered
10 cardiometabolic risk score ($p=0.05$) were significantly higher in children who
11 engaged in more prolonged sedentary bouts per day. The number of breaks in
12 sedentary time per day was not associated with any cardiometabolic risk factor, but
13 longer mean duration of daily breaks in sedentary time were associated with a lower
14 odds of having abdominal adiposity ($p=0.04$) and elevated diastolic blood pressure
15 ($p=0.01$). These associations may be mediated by engagement in light activity. This
16 study provides evidence that avoiding periods of prolonged uninterrupted sedentary
17 time may be important for reducing cardiometabolic disease risk in children.

18

19 **Introduction**

20 Cardiometabolic risk factors that independently predict cardiometabolic disease in
21 adults include abdominal obesity, hypertension, dyslipidaemia, and impaired fasting
22 glucose (Graham et al., 2007). The clustering of these risk factors confers additive
23 risk beyond the level predicted by the individual component (Golden et al., 2002).
24 This risk factor clustering is increasing in children, with the metabolic syndrome
25 prevalent in 8.6% of American youths (Johnson et al., 2009). This is concerning as
26 risk factor clustering persists into adulthood and increases subsequent risk of
27 cardiometabolic disease (Camhi & Katzmarzyk, 2010; Morrison, Friedman, & Gray-
28 McGuire, 2007). Low cardiorespiratory fitness is also a predictor of increased
29 cardiometabolic risk in children (Bailey, Boddy, Savory, Denton, & Kerr, 2012) and
30 the determinants of these health risk markers thus need to be identified.

31 Sedentary behaviour is defined as “any waking behaviour characterised by
32 an energy expenditure ≤ 1.5 METs while in a sitting or reclining position” (Sedentary
33 Behaviour Research Network, 2012). The manner in which sedentary time is
34 accumulated (i.e. engaging in prolonged uninterrupted bouts of sitting) has emerged
35 as a significant cardiometabolic disease risk factor with cross-sectional beneficial
36 associations observed between increased frequency of breaks in sedentary time
37 and cardiometabolic risk in adults (Healy et al., 2008), independent of total
38 sedentary time and moderate-to-vigorous physical activity (MVPA). The few studies
39 examining associations between sedentary bouts and breaks in sedentary time with
40 cardiometabolic risk in children have revealed conflicting findings or have not
41 provided a comprehensive analysis of different sedentary patterns (Altenburg et al.,
42 2015; Carson & Janssen, 2011; Colley et al., 2013; Saunders et al., 2013b). The
43 inconsistent findings may be due to the use of different operational definitions of
44 sedentary bouts and breaks in sedentary time. Several studies tolerated non-
45 sedentary activity within their sedentary bout definitions (Carson & Janssen, 2011;
46 Colley et al., 2013; Saunders et al., 2013b). These permitted interruptions in

47 sedentary time should not be tolerated as they may attenuate the detrimental effects
48 of prolonged sedentary time on cardiometabolic disease risk. Previous research has
49 also failed to examine the associations between patterns of sedentary time and
50 cardiorespiratory fitness in children.

51 The primary aims of this study were to examine the association of individual
52 cardiometabolic risk factors, clustered cardiometabolic risk, and cardiorespiratory
53 fitness in 10-14 year-old children with (a) the number of prolonged uninterrupted
54 bouts of sedentary time using an operational definition derived from experimental
55 studies and allowing zero tolerance above the sedentary activity cut-point, (b)
56 duration of prolonged sedentary bouts, (c) number of breaks in sedentary time, and
57 (d) mean duration of daily breaks in sedentary time.

58

59 **Methodology**

60 *Participants*

61 The participants investigated were part of the Health And Physical activity
62 Promotion in Youth (HAPPY) study and the data analysed in this report was
63 collected in 2008. Participants were 10-14 year-old children recruited on a voluntary
64 basis in 11 schools across Bedfordshire, UK, and baseline data from 45% of the
65 total sample was analysed in the present study. Participants were excluded from the
66 HAPPY study if they were on medication for high blood pressure or if they had heart
67 conditions, dizziness, or joint pain that could be exacerbated through exercise. As
68 part of the consent process, parents were given the option to remove their child
69 from the blood sampling procedure. Further participants were excluded if they did
70 not reach the inclusion criteria specified below for physical activity or
71 cardiorespiratory fitness assessment. Participants who consented to providing blood
72 samples engaged in significantly more light activity and MVPA than those who did
73 not consent ($p=0.02$ and 0.05 , respectively), while there was no difference in
74 sedentary behaviour variables ($p>0.05$). The HAPPY study received full ethical
75 approval from the University of Bedfordshire Ethics Review Board. Written informed
76 consent was obtained from participants' parents and verbal assent from the
77 participants before any test procedures.

78

79 *Measures*

80 Participants were required to fast from 9 pm the night before measurements were
81 performed. Body composition and blood measurements were taken between 8-10
82 am and participants were instructed to bring a snack with them to eat for breakfast
83 afterwards. Stature and waist circumference (WC) measured at the umbilicus were
84 recorded to the nearest 0.5 cm using the portable Leicester Height Measure (Seca,
85 Birmingham, UK) and an adjustable tape measure (Hoechstmass, Sulzbach,
86 Germany), respectively. Body mass and body fat% were recorded to the nearest 0.1

87 kg and 0.1%, respectively, using the Tanita BC-418 Segmental Body Composition
 88 Analyzer (Tanita Corp., Tokyo, Japan), which is valid for epidemiological studies
 89 assessing whole body fat in children (Luque et al., 2014). Body mass index (BMI)
 90 was calculated using the equation: $BMI = \text{body mass (kg)} \div \text{stature}^2 (\text{m}^2)$. UK
 91 reference values were used to calculate z-scores for height, weight, BMI, and WC
 92 (z-WC) (Cole, Freeman, & Preece, 1995; Freeman et al., 1995; McCarthy, Jarrett, &
 93 Crawley, 2001).

94 Sitting blood pressure was measured using an Omron M5-I automated
 95 oscillatory device (Omron Matsusaka Co. Ltd., Matsusaka, Japan) on the left arm
 96 after the participant had rested for 5 min. Three blood pressure readings were
 97 obtained with 2 min rest between each and the average of the lowest two readings
 98 recorded. Fasting blood samples (40 μl) were obtained using a finger prick method
 99 and analysed using a point-of-care Cholestech LDX Analyzer (Cholestech Corp.,
 100 Hayward, CA.) to determine total cholesterol (TC), high-density lipoprotein
 101 cholesterol (HDL), triglycerides, and blood glucose levels. This system is validated
 102 in adults (Parikh, Mochari, & Mosca, 2009) and is certified by the Centers for
 103 Disease Control Cholesterol Reference Method Laboratory Network, This system
 104 has been used in previous paediatric research (Ahrens et al., 2014).

105 Cardiorespiratory fitness was determined indirectly using a previously
 106 validated age- and sex-specific all-out progressive cycle ergometer test to
 107 exhaustion (Riddoch et al., 2005) and this took place a minimum of 90 min after the
 108 breakfast snack. Workloads increased every 3 min until volitional exhaustion
 109 occurred. A maximal effort was deemed as a final heart rate ≥ 185 bpm in addition to
 110 subjective observation from the researcher that the participant could not continue.
 111 Participants who did not achieve a maximal effort were excluded from the analysis.
 112 Power output (watts) was calculated as being equal to $W_1 + (W_2 \cdot t/180)$, where W_1
 113 is work rate at fully completed stage, W_2 is the work rate increment at final
 114 incomplete stage, and t is time in seconds at the final incomplete stage. $\dot{V}O_{2\text{max}}$ was

115 estimated using previously described formulae (Hansen, Froberg, Nielsen, &
 116 Hyldebrandt, 1989) and expressed as mL per kilogram of body mass per min (mL·
 117 $^{-1}/\text{kg}^{-1}/\text{min}^{-1}$). Estimated $\dot{V}O_{2\text{max}}$ using this approach correlates significantly with
 118 directly assessed $\dot{V}O_{2\text{max}}$ in boys and girls ($r=0.90$ and 0.95 , respectively, $p<0.01$)
 119 with a standard error of estimation of 3.2% (Hansen et al., 1989).

120 Participants were then asked to wear a tri-axial accelerometer (RT3®,
 121 Stayhealthy, Inc., Monrovia, CA) on their dominant hip to measure sedentary
 122 behaviour and physical activity over the next seven days during waking hours in 1-
 123 min epochs. Sequences of ≥ 10 min of consecutive zero counts were removed
 124 during the recoding process (Riddoch et al., 2004). The inclusion criteria for analysis
 125 were a minimum wear time of three days (Mattocks et al., 2008) and a minimum
 126 daily wear time of nine hours for weekdays (Mattocks et al., 2008) and eight hours
 127 for weekend days (Rowlands, Pilgrim, & Eston, 2008). Participants not meeting
 128 these criteria were excluded from the present analysis. There is currently substantial
 129 variation in cut-points used to define sedentary behaviour and physical activity
 130 intensities (Reilly et al., 2008). For this analysis, time spent sedentary (<420 counts
 131 per minute [cpm]), in light physical activity ($420-1859$ cpm), and in MVPA (≥ 1860
 132 cpm) was determined from a previous validation study in children (Chu, 2007). The
 133 sedentary cut-point was determined solely from non-ambulation activities (lying,
 134 sitting, and static standing) and the threshold of 420 cpm provided a sensitivity and
 135 specificity of 100% for distinguishing sedentary behaviour from low-intensity
 136 ambulation (Chu, 2007). The total number of prolonged sedentary bouts (≥ 20 min of
 137 uninterrupted sedentary time), mean duration of prolonged sedentary bouts, number
 138 of breaks in sedentary time (defined as a sedentary bout interrupted by ≥ 1 min of
 139 light activity or MVPA), and mean duration of daily breaks in sedentary time were
 140 calculated. All physical activity and sedentary variables were calculated each day
 141 and then averaged across valid days. The 20 min cut-point to define a prolonged

142 sedentary bout was based on experimental research in children and young adults
143 demonstrating deleterious cardiometabolic effects of engaging in ≥ 20 min
144 uninterrupted prolonged sitting bouts (Bailey & Locke, 2015; Belcher et al., 2015).
145 The 1 min cut-point to define a break in sedentary time was based on evidence
146 demonstrating beneficial associations with cardiometabolic risk in adults (Healy et
147 al., 2008). Similar to previous research, participants were stratified into groups (low
148 and high) based on the sample mean for each individual sedentary behaviour
149 variable (Carson & Janssen, 2011).

150 Abdominal obesity was defined as WC $\geq 90^{\text{th}}$ percentile for age and sex
151 (McCarthy et al., 2001). Hypercholesterolaemia was defined as TC ≥ 5.17 mmol/L
152 (National Cholesterol Education Panel, 1991). The National Cholesterol Education
153 Program's Pediatric Panel Report (1991) gives a range of 0.91-1.16 mmol/L for
154 borderline low HDL levels and 1.02-1.46 mmol/L for borderline high triglyceride
155 concentrations for all sexes and ages. Therefore, the midpoint of these ranges was
156 used as the 10^{th} percentile value to define low HDL (≤ 1.03 mmol/L) and the 90^{th}
157 percentile value to define hypertriglyceridaemia (≥ 1.24 mmol/L) (Cook, Weitzman,
158 Auinger, Nguyen, & Dietz, 2003). Impaired fasting glucose was defined as ≥ 5.6
159 mmol/L (Zimmet et al., 2007). High systolic and diastolic blood pressure was
160 defined as $\geq 90^{\text{th}}$ percentile for age, sex, and height (National High Blood Pressure
161 Education Program Working Group on High Blood Pressure in Children and
162 Adolescents, 2004). Metabolic syndrome was defined as having ≥ 3 of the following
163 cardiometabolic risk factors: abdominal obesity (high WC), low HDL,
164 hypertriglyceridaemia, high systolic or diastolic blood pressure, and impaired fasting
165 glucose. Cardiorespiratory fitness values $>37.0 \text{ mL}^{-1}/\text{kg}^{-1}/\text{min}^{-1}$ for girls and >42.1
166 $\text{mL}^{-1}/\text{kg}^{-1}/\text{min}^{-1}$ for boys represented a high cardiorespiratory fitness level, while
167 values below these levels represented low cardiorespiratory fitness (Ruiz et al.,
168 2007).

169 A continuous clustered cardiometabolic risk score was also calculated as
170 this approach increases statistical power (Ragland, 1992) and is used in paediatric
171 research (Saunders et al., 2013b). First, TC:HDL ratio and triglycerides were non-
172 normally distributed and were log-transformed. The clustered risk score was then
173 constructed by summing the standardised z-scores for the following continuously
174 distributed variables: WC, diastolic blood pressure, TC:HDL ratio, triglycerides, and
175 blood glucose. Participants were then assigned to a 'normal' or 'at-risk' clustered
176 cardiometabolic risk group with high risk defined as ≥ 1 SD (2.77) in risk score above
177 the pooled mean (Andersen et al., 2006). A non-obesity clustered risk score was
178 also calculated by removing z-WC (Ekelund et al., 2007). High risk for the non-
179 obesity clustered risk score was defined as ≥ 1 SD (2.28) in risk score above the
180 pooled mean.

181 Potential covariates included age, sex, ethnicity (recorded as white or non-
182 white), and socioeconomic status, which was determined using the 2007 Indices of
183 Multiple Deprivation (Department for Communities and Local Government, 2008).

184

185 *Statistical analysis*

186 Analyses were completed using IBM SPSS Statistics version 21.0 (SPSS Inc.,
187 Armonk, N.Y., USA). Descriptive data is expressed as mean \pm SD. Partial correlation
188 analysis explored relationships between sedentary behaviour variables and
189 cardiometabolic risk factors. Of the potential covariates, sex and ethnicity were
190 significantly related with ≥ 1 cardiometabolic risk factor and were thus adjusted for in
191 the analysis in addition to total sedentary time (except where total sedentary time
192 was an independent variable), MVPA, and accelerometer wear time (Altenburg et
193 al., 2015). Abdominal obesity (z-WC) was additionally adjusted for in the analysis
194 exploring relationships with cardiorespiratory fitness and the non-obesity clustered
195 cardiometabolic risk score.

196 Multiple logistic regression models were used to examine the odds of having
197 individual and clustered cardiometabolic risk factors according to high and low
198 levels for the sedentary bout and breaks in sedentary time variables. Participants
199 categorised into the low group were the reference comparator for each independent
200 sedentary behaviour variable and dependent cardiometabolic risk factors, except for
201 HDL where participants with high levels were the reference comparator. All
202 regression models were adjusted for the same variables as described above for the
203 correlation analysis (model 1). Light activity may be independently associated with
204 cardiometabolic risk (Healy et al., 2007) and all regression models were therefore
205 performed again additionally adjusting for this variable to explore whether light
206 activity mediates the associations between sedentary behaviour variables and
207 cardiometabolic risk (model 2). Data for the regression analysis is expressed as
208 odds ratio (OR) and 95% confidence interval (CI). The level of significance was set
209 at $p \leq 0.05$.
210

211 **Results**

212 Of the 249 participants from the HAPPY study, 93 did not provide consent to blood
 213 sampling and were excluded from the present analysis. Of the remaining 156
 214 participants, 45 participants did not provide valid accelerometry data and were
 215 excluded from the present analysis. This resulted in 111 participants (66 girls,
 216 11.8±1.4 years) being included in the final analysis. Three participants did not
 217 achieve a maximal effort during the cardiorespiratory fitness test and associations
 218 between sedentary behaviour variables and cardiorespiratory fitness are thus
 219 reported for 108 participants.

220

221 Table 1 shows the descriptive characteristics of the participants. The prevalence of
 222 abdominal adiposity was 17.1%; hypercholesterolaemia 6.3%; low HDL 12.6%;
 223 hypertriglyceridaemia 17.1%; elevated systolic blood pressure 18.9%; elevated
 224 diastolic blood pressure 18.0%; and impaired fasting glucose 11.7%. Metabolic
 225 syndrome was prevalent in 7.2% of participants, 16.2% had an increased clustered
 226 cardiometabolic risk score, and 18.9% had an increased non-obesity clustered
 227 cardiometabolic risk score. The prevalence of low cardiorespiratory fitness was
 228 35.2%.

229

230 After adjusting for sex, ethnicity, total sedentary time, MVPA, and accelerometer
 231 wear time, the duration of prolonged sedentary bouts was significantly positively
 232 correlated with systolic blood pressure (Table 2). The number of breaks in
 233 sedentary time was significantly negatively correlated with cardiorespiratory fitness.
 234 The mean duration of daily breaks in sedentary time was significantly positively
 235 correlated with cardiorespiratory fitness and significantly negatively correlated with
 236 total cholesterol. Total sedentary time was significantly negatively correlated with
 237 abdominal adiposity.

238

239 The multivariate adjusted ORs (and 95% CIs) for having adverse cardiometabolic
 240 risk factor levels across low and high groups for the number of prolonged sedentary
 241 bouts (5.5 ± 1.2 and 8.4 ± 0.8 for the low and high groups, respectively), duration of
 242 prolonged sedentary bouts (33.25 ± 2.36 and 40.90 ± 4.17 min/day for the low and
 243 high groups, respectively), number of breaks in sedentary time (53.0 ± 6.4 and
 244 72.6 ± 10.4 for the low and high groups, respectively), and mean duration of daily
 245 breaks in sedentary time (3.15 ± 0.38 and 4.46 ± 0.63 min/day for the low and high
 246 groups, respectively) are presented in Table 3. After adjusting for sex, ethnicity, total
 247 sedentary time, MVPA, and accelerometer wear time (model 1), the odds of having
 248 hypertriglyceridaemia, increased clustered cardiometabolic risk score, and
 249 increased non-obesity clustered cardiometabolic risk score were significantly higher
 250 in children who engaged in more prolonged sedentary bouts per day. The duration
 251 of prolonged sedentary bouts and the number of breaks in sedentary time were not
 252 significantly associated with cardiometabolic risk. Children who engaged in longer
 253 mean duration daily breaks in sedentary time had significantly lower odds of having
 254 abdominal obesity and elevated diastolic blood pressure. When additionally
 255 adjusting for light activity (model 2), the associations between the number of
 256 prolonged sedentary bouts with hypertriglyceridaemia (OR=3.91, 95% CI 0.79,
 257 19.29, $p=0.10$), clustered cardiometabolic risk score (4.31; 0.79, 23.60, $p=0.09$), and
 258 the non-obesity clustered cardiometabolic risk score (4.19; 0.87, 20.29, $p=0.08$)
 259 were attenuated and no longer significant. The higher odds of having abdominal
 260 obesity in children who engaged in longer duration prolonged sedentary bouts
 261 strengthened and became significant (5.00; 0.98, 25.43, $p=0.05$). The lower odds of
 262 having abdominal obesity (0.10; 0.01, 0.80, $p=0.03$) and elevated diastolic blood
 263 pressure (0.09; 0.01, 0.68, $p=0.02$) in children who engaged in longer mean
 264 duration daily breaks in sedentary time was unaffected.

265 **Discussion**

266 The main findings of this study were that engaging in more prolonged sedentary
267 bouts per day was significantly associated with increased cardiometabolic risk in 10-
268 14 year-old children, while engaging in longer mean duration daily breaks in
269 sedentary time was significantly associated with lower cardiometabolic risk .

270 The children in this study engaged in an average of seven prolonged
271 sedentary bouts (≥ 20 min) per day lasting an average 37 min. In other studies
272 applying the strictest definition of uninterrupted sedentary time (i.e. zero tolerance),
273 Saunders et al. (2013b) found that 8-11 year-olds engaged in five sedentary bouts
274 per day lasting 15-29 min, whereas Altenburg et al. (2015) reported 10-13 year-old
275 children engaged in an average of two sedentary bouts lasting ≥ 20 min per day.
276 However, Altenburg et al. (2015) used a different accelerometer model to the
277 present study and a shorter epoch length for data capture (15-s versus 1-min in the
278 present study), which could explain the discrepancies observed.

279 Engaging in more prolonged sedentary bouts was associated with higher
280 odds of hypertriglyceridaemia and increased clustered cardiometabolic risk
281 (independent of abdominal obesity) in the present study. It may thus be appropriate
282 for paediatric health promotion strategies to target reductions in the number of
283 prolonged sedentary bouts accumulated per day to reduce cardiometabolic disease
284 risk. In 6-19 year-old children, no associations between sedentary time
285 accumulated in ≥ 20 min and ≥ 30 min bouts and cardiometabolic risk were observed
286 (Carson & Janssen, 2011; Colley et al., 2013). This was in addition to ≥ 30 , 60, 100,
287 and 120 min sedentary bout durations, although positive associations between
288 bouts lasting ≥ 40 and 80 min with anthropometrics were observed in a subgroup of
289 10-14 year-old boys (Colley et al., 2013). Each of these above studies permitted
290 non-sedentary activity within their sedentary bout definitions, which may explain the
291 lack of associations reported. When allowing zero tolerance time within sedentary
292 bouts, Altenburg et al. (2015) did not observe associations between ≥ 20 min

293 sedentary bouts and cardiometabolic risk, but did report weak associations with
294 sedentary time accumulated in bouts of ≥ 5 , 10, and 30 min. The reason prolonged
295 bouts of ≥ 20 min was not associated with cardiometabolic risk is not clear but may
296 be due to the low number of ≥ 20 min sedentary bouts observed ($n=2$), thus
297 providing insufficient statistical power (Altenburg et al., 2015). Saunders et al.
298 (2013b) allowed zero tolerance time in their sedentary bout definition and reported a
299 number of negative and positive associations of sedentary bout durations lasting 1-4
300 min, 5-9 min, 10-14 min, 15-29 min, and ≥ 30 min with various cardiometabolic risk
301 factors. However, using this delimited approach makes the findings difficult to
302 interpret and compare to the present study. Future studies should thus use
303 consistent definitions of sedentary time bouts and patterns. Based on previous
304 experimental research in children (Belcher et al., 2015) and the findings of the
305 present study, we suggest defining a prolonged sedentary bout as ≥ 20 min of
306 uninterrupted sedentary time with zero tolerance of non-sedentary activity within
307 bouts.

308 Adjusting for light activity attenuated the associations between the number of
309 prolonged sedentary bouts with hypertriglyceridaemia and clustered cardiometabolic
310 risk. It is unknown whether light activity would have mediated associations between
311 sedentary bouts and breaks in sedentary time in previous studies as no adjustment
312 for this variable was made (Altenburg et al., 2015; Carson & Janssen, 2011; Colley
313 et al., 2013; Saunders et al., 2013b). As light activity may be an important mediating
314 factor, future studies should account for this variable to identify true independent
315 associations between sedentary behaviour patterns and cardiometabolic risk.

316 Children in this study engaged in an average of 63 breaks in sedentary time
317 per day. In 6-19 year-olds, the number of daily breaks in sedentary time was 81 and
318 85 in boys and girls, respectively (Colley et al., 2013), Carson, Stone, and Faulkner
319 (2014) reported that 11 year-old children engaged in 56 breaks per hour, which is
320 substantially higher than that reported previously and in the present study. However,

321 Carson et al. (2014) defined a break in sedentary time as any 5-s epoch change
322 above the sedentary activity cut-point, whereas a break was defined as an
323 interruption lasting ≥ 1 min in the present study and previous research (Colley et al.,
324 2013). The duration of breaks in sedentary time has not been reported in previous
325 paediatric research. The mean duration of daily breaks in sedentary time in the
326 present study was 3.8 min, which is comparable to adults (Healy et al., 2008).
327 Definitions of a break in sedentary time varies widely (Chastin, Egerton, Leask, &
328 Stamatakis, 2015) and it is thus difficult to propose a standardised definition for this
329 variable. Further research should establish the minimum duration of a break in
330 sedentary time required to produce cardiometabolic benefits.

331 The number of breaks in sedentary time was not associated with
332 cardiometabolic risk or cardiorespiratory fitness in the present study, which supports
333 previous findings (Carson & Janssen, 2011). However, in 8-11 year-old children, the
334 number of breaks in sedentary time was negatively associated with clustered
335 cardiometabolic risk (Saunders et al., 2013b). The reason for this disparity is not
336 clear as both the present study and Saunders et al. (2013b) used 1-min
337 accelerometer epochs and applied the same definition of a break in sedentary time.
338 Saunders et al. (2013b) studied children with a family history of obesity who were
339 slightly younger than the current sample. The present study used a triaxial
340 accelerometer, whereas Saunders et al. (2013b) used a uniaxial model that only
341 captures vertical accelerations and these could be explanatory factors. The present
342 study is the first to examine associations between the mean duration of daily breaks
343 in sedentary time and cardiometabolic risk in children. Longer mean duration daily
344 breaks in sedentary time were associated with lower odds of abdominal obesity and
345 elevated diastolic blood pressure. This suggests that in addition to reducing the
346 number of prolonged sedentary bouts, children should also increase the duration of
347 breaks in sedentary time to reduce cardiometabolic disease risk.

348 The present study is the first to examine associations between prolonged
349 sedentary time and cardiorespiratory fitness in children. When participants were
350 stratified into low and high groups for each of the sedentary behaviour variables,
351 there were no associations with cardiorespiratory fitness. However, the number of
352 breaks in sedentary time was negatively correlated with cardiorespiratory fitness,
353 while the mean duration of daily breaks in sedentary time was positively correlated.
354 The greater volume of physical activity accumulated through longer mean duration
355 daily breaks in sedentary time may be sufficient to promote a higher level of
356 cardiorespiratory fitness. The reason more breaks in sedentary time was correlated
357 with lower cardiorespiratory fitness is not clear and is suggestive of a complex
358 interaction between this health risk marker and sedentary behaviour patterns.
359 Further research is needed to establish the importance of sedentary bouts and
360 breaks in sedentary time for cardiorespiratory fitness in children.

361 There are several potential mechanisms that could explain the detrimental
362 association of prolonged sedentary bouts with cardiometabolic risk. In adults,
363 imposed prolonged sedentary behaviour can cause an acute reduction in insulin
364 action, lower HDL, and increase glucose and triglyceride concentrations (Saunders,
365 Larouche, Colley, & Tremblay, 2012). These deleterious effects may be partially
366 mediated by reductions in lipoprotein lipase activity, which facilitates uptake of free
367 fatty acids into muscle and adipose tissue, and increases in glucose uptake
368 stimulated by insulin and the glucose transporter protein GLUT-4 (Hamilton,
369 Hamilton, & Zderic, 2007). Imposed sedentary behaviour causes an acute decline in
370 vascular function in adults and young females, which appears to be mediated by
371 reductions in shear stress that influences the structure of blood vessels and
372 endothelial cell function (McManus et al., 2015; Thosar, Bielko, Mather, Johnston, &
373 Wallace, 2015). In adults, the acute declines in cardiometabolic function can be
374 mitigated by breaking up prolonged sedentary time with regular short bouts of
375 physical activity (Chastin et al., 2015), whereas in children the evidence is not

376 consistent (Belcher et al., 2015; Heden, Liu, Park, Winn, & Kanaley, 2015;
377 McManus et al., 2015; Ross, Hinckson, & Zinn, 2015; Saunders et al., 2013a). With
378 regards to abdominal obesity, it is plausible that children who engage in longer
379 duration breaks in sedentary time expend more daily energy and therefore store
380 less energy as fat.

381 The strengths of this study include objectively measured sedentary
382 behaviour patterns and cardiometabolic risk factors and detailed analysis of
383 sedentary time using strict definitions. Limitations of this study include the cross-
384 sectional design, thus limiting conclusions regarding causality. There is a lack of
385 consensus regarding the most appropriate cut-off points for metabolic syndrome risk
386 factors in children and this could affect the associations observed. As a waist-worn
387 accelerometer was used, it is possible that some light activities (e.g. standing still)
388 were misclassified as sedentary behaviour, which may have led to an
389 overestimation of sedentary time. The use of 1-min epochs and potential
390 measurement error of the accelerometer may have led to misclassification of
391 sedentary time or physical activity, which could have affected the associations
392 observed and the appropriateness of the standardised recommendations for
393 sedentary bouts and breaks in sedentary time. Future studies should consider the
394 instrument and epoch duration to be used so that definitive conclusions regarding
395 the association of sedentary behaviour patterns with cardiometabolic risk in children
396 can be made. A minimum of three days accelerometer wear time was required in
397 the present analysis and periods of ≥ 10 min of consecutive zero accelerometer
398 counts were defined as non-wear time. A minimum of three days is often used in the
399 literature (Toftager et al., 2013) but the minimum number of days to produce reliable
400 data using the RT3® accelerometer is unknown. Previous research has applied
401 criteria of between 10 and 60 min of consecutive zero counts (Toftager et al., 2013).
402 The most appropriate criteria to classify non-wear time is unknown and a consensus
403 is needed to provide greater comparability between studies. Adjusting for light

404 activity attenuated some of the associations observed between the number of
405 prolonged sedentary bouts and cardiometabolic risk markers. Although these
406 associations became non-significant, it is possible that significance would have
407 remained with a larger sample size. There was no measure of maturation available
408 in this study, which could have confounded the associations observed as transient
409 changes in cardiometabolic risk occur during puberty (Moran et al., 2008). The
410 potential confounding effects of dietary intake and eating behaviour that are
411 independently associated with cardiometabolic risk (Eloranta et al., 2014) were also
412 not accounted for. Other potential confounding factors not accounted for include
413 smoking and the presence of Type 1 or Type 2 diabetes.

414 In conclusion, the findings of the present study demonstrate that prolonged
415 sedentary bouts and the mean duration of daily breaks in sedentary time are
416 independently associated with cardiometabolic risk in 10-14 year-old children.
417 Future research should aim to use standardised methods of measurement and
418 definitions of sedentary bouts and breaks in sedentary time. These standardised
419 approaches should then be utilised in longitudinal and experimental studies to
420 determine which patterns of sedentary time are important for paediatric health.

421

422

423 **References**

- 424 Ahrens, W., Moreno, L. A., Marild, S., Molnar, D., Siani, A., De Henauw, S., . . .
425 Pigeot, I. (2014). Metabolic syndrome in young children: definitions and
426 results of the IDEFICS study. *Int J Obes (Lond)*, 38 Suppl 2, S4-14.
- 427 Altenburg, T. M., de Niet, M., Verloigne, M., De Bourdeaudhuij, I., Androutsos, O.,
428 Manios, Y., . . . Chinapaw, M. J. (2015). Occurrence and duration of various
429 operational definitions of sedentary bouts and cross-sectional associations
430 with cardiometabolic health indicators: the ENERGY-project. *Prev Med*, 71,
431 101-106.
- 432 Andersen, L. B., Harro, M., Sardinha, L. B., Froberg, K., Ekelund, U., Brage, S., &
433 Anderssen, S. A. (2006). Physical activity and clustered cardiovascular risk
434 in children: a cross-sectional study (The European Youth Heart Study).
435 *Lancet*, 368(9532), 299-304.
- 436 Bailey, D. P., Boddy, L. M., Savory, L. A., Denton, S. J., & Kerr, C. J. (2012).
437 Associations between cardiorespiratory fitness, physical activity and
438 clustered cardiometabolic risk in children and adolescents: the HAPPY
439 study. *Eur J Pediatr*, 171(9), 1317-1323.
- 440 Bailey, D. P., & Locke, C. D. (2015). Breaking up prolonged sitting with light-
441 intensity walking improves postprandial glycemia, but breaking up sitting with
442 standing does not. *J Sci Med Sport*, 18(3), 294-298.
- 443 Belcher, B. R., Berrigan, D., Papachrisotopoulou, A., Brady, S. M., Bernstein, S. B.,
444 Brychta, R. J., . . . Yanovski, J. A. (2015). Effects of Interrupting Children's
445 Sedentary Behaviors With Activity on Metabolic Function: A Randomized
446 Trial. *J Clin Endocrinol Metab*, 100(10), 3735-3743.

- 447 Camhi, S. M., & Katzmarzyk, P. T. (2010). Tracking of cardiometabolic risk factor
448 clustering from childhood to adulthood. *Int J Pediatr Obes*, 5(2), 122-129.
- 449 Carson, V., & Janssen, I. (2011). Volume, patterns, and types of sedentary behavior
450 and cardio-metabolic health in children and adolescents: a cross-sectional
451 study. *BMC Public Health*, 11, 274.
- 452 Carson, V., Stone, M., & Faulkner, G. (2014). Patterns of sedentary behavior and
453 weight status among children. *Pediatr Exerc Sci*, 26(1), 95-102.
- 454 Chastin, S. F., Egerton, T., Leask, C., & Stamatakis, E. (2015). Meta-analysis of the
455 relationship between breaks in sedentary behavior and cardiometabolic
456 health. *Obesity (Silver Spring)*, 23(9), 1800-1810.
- 457 Chu, E. Y., McManus, A. M., Yu, C. C. (2007). Calibration of the RT3 accelerometer
458 for ambulation and nonambulation in children. *Med Sci Sports Exerc*, 39(11),
459 2085-2091.
- 460 Cole, T. J., Freeman, J. V., & Preece, M. A. (1995). Body mass index reference
461 curves for the UK, 1990. *Arch Dis Child*, 73(1), 25-29.
- 462 Colley, R. C., Garrigué, D., Janssen, I., Wong, S. L., Saunders, T. J., Carson, V., &
463 Tremblay, M. S. (2013). The association between accelerometer-measured
464 patterns of sedentary time and health risk in children and youth: results from
465 the Canadian Health Measures Survey. *BMC Public Health*, 13, 200.
- 466 Cook, S., Weitzman, M., Auinger, P., Nguyen, M., & Dietz, W. H. (2003). Prevalence
467 of a metabolic syndrome phenotype in adolescents: findings from the third
468 National Health and Nutrition Examination Survey, 1988-1994. *Arch Pediatr
469 Adolesc Med*, 157(8), 821-827.

- 470 Department for Communities and Local Government. (2008). *The English indices of*
471 *deprivation 2007*. Wetherby: Communities and Local Government
472 Publications.
- 473 Ekelund, U., Anderssen, S. A., Froberg, K., Sardinha, L. B., Andersen, L. B., &
474 Brage, S. (2007). Independent associations of physical activity and
475 cardiorespiratory fitness with metabolic risk factors in children: the European
476 Youth Heart Study. *Diabetologia*, 50(9), 1832-1840.
- 477 Eloranta, A. M., Lindi, V., Schwab, U., Kiiskinen, S., Venalainen, T., Lakka, H. M., . .
478 . Lakka, T. A. (2014). Dietary factors associated with metabolic risk score in
479 Finnish children aged 6-8 years: the PANIC study. *Eur J Nutr*, 53(6), 1431-
480 1439.
- 481 Freeman, J. V., Cole, T. J., Chinn, S., Jones, P. R., White, E. M., & Preece, M. A.
482 (1995). Cross sectional stature and weight reference curves for the UK,
483 1990. *Arch Dis Child*, 73(1), 17-24.
- 484 Golden, S. H., Folsom, A. R., Coresh, J., Sharrett, A. R., Szklo, M., & Brancati, F.
485 (2002). Risk factor groupings related to insulin resistance and their
486 synergistic effects on subclinical atherosclerosis: the atherosclerosis risk in
487 communities study. *Diabetes*, 51(10), 3069-3076.
- 488 Graham, I., Atar, D., Borch-Johnsen, K., Boysen, G., Burell, G., Cifkova, R., . . .
489 Dudina, A. (2007). European guidelines on cardiovascular disease
490 prevention in clinical practice: executive summary: Fourth Joint Task Force
491 of the European Society of Cardiology and Other Societies on
492 Cardiovascular Disease Prevention in Clinical Practice. *Eur Heart J*, 28(19),
493 2375-2414.

- 494 Hamilton, M. T., Hamilton, D. G., & Zderic, T. W. (2007). Role of low energy
495 expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and
496 cardiovascular disease. *Diabetes*, 56(11), 2655-2667.
- 497 Hansen, H. S., Froberg, K., Nielsen, J. R., & Hyldebrandt, N. (1989). A new
498 approach to assessing maximal aerobic power in children: the Odense
499 School Child Study. *Eur J Appl Physiol Occup Physiol*, 58(6), 618-624.
- 500 Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z., &
501 Owen, N. (2007). Objectively measured light-intensity physical activity is
502 independently associated with 2-h plasma glucose. *Diabetes Care*, 30(6),
503 1384-1389.
- 504 Healy, G. N., Dunstan, D. W., Salmon, J., Cerin, E., Shaw, J. E., Zimmet, P. Z., &
505 Owen, N. (2008). Breaks in sedentary time: beneficial associations with
506 metabolic risk. *Diabetes Care*, 31(4), 661-666.
- 507 Heden, T. D., Liu, Y., Park, Y. M., Winn, N. C., & Kanaley, J. A. (2015). Walking
508 Reduces Postprandial Insulin Secretion in Obese Adolescents Consuming a
509 High-Fructose or High-Glucose Diet. *J Phys Act Health*, 12(8), 1153-1161.
- 510 Johnson, W. D., Kroon, J. J., Greenway, F. L., Bouchard, C., Ryan, D., &
511 Katzmarzyk, P. T. (2009). Prevalence of risk factors for metabolic syndrome
512 in adolescents: National Health and Nutrition Examination Survey
513 (NHANES), 2001-2006. *Arch Pediatr Adolesc Med*, 163(4), 371-377.
- 514 Luque, V., Closa-Monasterolo, R., Rubio-Torrents, C., Zaragoza-Jordana, M., Ferre,
515 N., Gispert-Llaurado, M., & Escribano, J. (2014). Bioimpedance in 7-year-old
516 children: validation by dual X-ray absorptiometry - part 1: assessment of
517 whole body composition. *Ann Nutr Metab*, 64(2), 113-121.

- 518 Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., . . . Riddoch, C.
519 (2008). Use of accelerometers in a large field-based study of children:
520 protocols, design issues, and effects on precision. *J Phys Act Health*, 5
521 *Suppl 1*, S98-111.
- 522 McCarthy, H. D., Jarrett, K. V., & Crawley, H. F. (2001). The development of waist
523 circumference percentiles in British children aged 5.0-16.9 y. *Eur J Clin Nutr*,
524 55(10), 902-907.
- 525 McManus, A. M., Ainslie, P. N., Green, D. J., Simair, R. G., Smith, K., & Lewis, N.
526 (2015). Impact of prolonged sitting on vascular function in young girls. *Exp*
527 *Physiol*, 100(11), 1379-1387.
- 528 Moran, A., Jacobs, D. R., Jr., Steinberger, J., Steffen, L. M., Pankow, J. S., Hong,
529 C. P., & Sinaiko, A. R. (2008). Changes in insulin resistance and
530 cardiovascular risk during adolescence: establishment of differential risk in
531 males and females. *Circulation*, 117(18), 2361-2368.
- 532 Morrison, J. A., Friedman, L. A., & Gray-McGuire, C. (2007). Metabolic syndrome in
533 childhood predicts adult cardiovascular disease 25 years later: the Princeton
534 Lipid Research Clinics Follow-up Study. *Pediatrics*, 120(2), 340-345.
- 535 National Cholesterol Education Panel. (1991). *Report of the Expert Panel on Blood*
536 *Cholesterol Levels in Children and Adolescents*. Bethesda, Md: National
537 *Institute of Health*, 1991. NIH Publication No. 91-2732.
- 538 National High Blood Pressure Education Program Working Group on High Blood
539 Pressure in Children and Adolescents. (2004). The fourth report on the
540 diagnosis, evaluation, and treatment of high blood pressure in children and
541 adolescents. *Pediatrics*, 114(2 Suppl 4th Report), 555-576.

- 542 Parikh, P., Mochari, H., & Mosca, L. (2009). Clinical utility of a fingerstick technology
543 to identify individuals with abnormal blood lipids and high-sensitivity C-
544 reactive protein levels. *Am J Health Promot*, 23(4), 279-282.
- 545 Ragland, D. R. (1992). Dichotomizing continuous outcome variables: dependence of
546 the magnitude of association and statistical power on the cutpoint.
547 *Epidemiology*, 3(5), 434-440.
- 548 Reilly, J. J., Penpraze, V., Hislop, J., Davies, G., Grant, S., & Paton, J. Y. (2008).
549 Objective measurement of physical activity and sedentary behaviour: review
550 with new data. *Arch Dis Child*, 93(7), 614-619.
- 551 Riddoch, C., Edwards, D., Page, A., Froberg, K., Anderssen, S. A., Wedderkopp,
552 N., . . . Andersen, L. B. (2005). The European Youth Heart Study -
553 cardiovascular disease risk factors in children: rationale, aims, study design,
554 and validation of methods. *J Phys Act Health*, 2(1), 115-129.
- 555 Riddoch, C. J., Bo Andersen, L., Wedderkopp, N., Harro, M., Klasson-Heggebo, L.,
556 Sardinha, L. B., . . . Ekelund, U. (2004). Physical activity levels and patterns
557 of 9- and 15-yr-old European children. *Med Sci Sports Exerc*, 36(1), 86-92.
- 558 Ross, K., Hinckson, A., & Zinn, C. (2015). Effect of Intermittent Sitting time on Acute
559 Postprandial Lipemia in Children. *Journal of Clinical & Translational*
560 *Endocrinology*, 2(2), 72-76.
- 561 Rowlands, A. V., Pilgrim, E. L., & Eston, R. G. (2008). Patterns of habitual activity
562 across weekdays and weekend days in 9-11-year-old children. *Prev Med*,
563 46(4), 317-324.
- 564 Ruiz, J. R., Ortega, F. B., Rizzo, N. S., Villa, I., Hurtig-Wennlof, A., Oja, L., &
565 Sjostrom, M. (2007). High cardiovascular fitness is associated with low

- 566 metabolic risk score in children: the European Youth Heart Study. *Pediatr*
567 *Res*, 61(3), 350-355.
- 568 Saunders, T. J., Larouche, R., Colley, R. C., & Tremblay, M. S. (2012). Acute
569 sedentary behaviour and markers of cardiometabolic risk: a systematic
570 review of intervention studies. *J Nutr Metab*, 2012, 712435.
- 571 Saunders, T. J., Chaput, J. P., Goldfield, G. S., Colley, R. C., Kenny, G. P., Doucet,
572 E., & Tremblay, M. S. (2013a). Prolonged sitting and markers of
573 cardiometabolic disease risk in children and youth: a randomized crossover
574 study. *Metabolism*, 62(10), 1423-1428.
- 575 Saunders, T. J., Tremblay, M. S., Mathieu, M. E., Henderson, M., O'Loughlin, J.,
576 Tremblay, A., . . . group, Q. c. r. (2013b). Associations of sedentary
577 behavior, sedentary bouts and breaks in sedentary time with cardiometabolic
578 risk in children with a family history of obesity. *PLoS One*, 8(11), e79143.
- 579 Sedentary Behaviour Research Network. (2012). Letter to the editor: standardized
580 use of the terms "sedentary" and "sedentary behaviours". *Appl Physiol Nutr*
581 *Metab*, 37(3), 540-542.
- 582 Thosar, S. S., Bielko, S. L., Mather, K. J., Johnston, J. D., & Wallace, J. P. (2015).
583 Effect of Prolonged Sitting and Breaks in Sitting Time on Endothelial
584 Function. *Med Sci Sports Exerc*, 47(4), 843-849.
- 585 Toftager, M., Kristensen, P. L., Oliver, M., Duncan, S., Christiansen, L. B., Boyle, E.,
586 . . . Troelsen, J. (2013). Accelerometer data reduction in adolescents: effects
587 on sample retention and bias. *Int J Behav Nutr Phys Act*, 10, 140.

Sedentary patterns and cardiometabolic risk

- 588 Zimmet, P., Alberti, K. G., Kaufman, F., Tajima, N., Silink, M., Arslanian, S., . . .
589 Caprio, S. (2007). The metabolic syndrome in children and adolescents - an
590 IDF consensus report. *Pediatr Diabetes*, 8(5), 299-306.
- 591

592 **Table 1** Descriptives for 10-14 year-old UK children

	Total (n=111)
Age (years)	11.8±1.4
Gender (%)	
Male	34
Female	66
Ethnicity (%)	
White	78
Non-white	22
z-height	0.36±1.01
z-weight	0.11±1.14
Body fat%	20.7±6.6
Body mass index z-score	-0.18±1.33
Cardiometabolic risk markers	
Waist circumference z-score	0.16±1.50
Systolic blood pressure (mm Hg)	108.7±9.7
Diastolic blood pressure (mm Hg)	68.6±6.9
Total cholesterol (mmol/L)	3.93±0.69
HDL (mmol/L)	1.43±0.39
TC:HDL ratio	2.95±1.07
Triglycerides (mmol/L)	0.85±0.49
Blood glucose (mmol/L)	5.04±0.46
Cardiorespiratory fitness (mL ⁻¹ /kg ⁻¹ /min ⁻¹)	42.06±9.54
Accelerometer-derived variables	
Number of prolonged sedentary bouts per day	7.0±1.8
Duration of prolonged sedentary bouts (min/day)	37.11±5.12
Number of breaks in sedentary time per day	62.9±13.0
Mean duration of daily breaks in sedentary time (min/day)	3.80±0.83
Total sedentary time (min/day)	504.02±80.53
Light physical activity (min/day)	182.44±47.01
Moderate-to-vigorous physical activity (min/day)	45.04±26.35
Total wear time (min/day)	731.84±72.87

593 Data presented as mean±SD.

594 HDL, high-density lipoprotein cholesterol; TC, total cholesterol.

595 n=108 for cardiorespiratory fitness.

596

Sedentary patterns and cardiometabolic risk

Table 2 Partial correlations between sedentary time and patterns and cardiometabolic risk factors in 10-14 year-old children

	Total sedentary time (min/day)	Number of prolonged sedentary bouts per day	Duration of prolonged sedentary bouts (min/day)	Number of breaks in sedentary time per day	Mean duration of daily breaks in sedentary time (min/day)
z-WC	-0.23	-0.02	0.11	0.05	-0.09
Total cholesterol (mmol/L)	0.02	-0.09	-0.09	0.09	-0.24
HDL (mmol/L)	0.02	-0.12	0.02	-0.03	0.07
Triglycerides (mmol/L) ^a	-0.16	0.14	0.04	-0.18	0.09
Blood glucose (mmol/L)	0.12	0.07	0.08	-0.12	0.08
Systolic blood pressure (mmHg)	-0.09	0.05	0.21	-0.06	-0.03
Diastolic blood pressure (mmHg)	-0.16	0.05	0.13	0.03	-0.07
Clustered cardiometabolic risk score	-0.12	0.12	0.12	-0.06	-0.08
Non-obesity clustered cardiometabolic risk score	-0.01	0.16	0.02	-0.11	-0.05
Cardiorespiratory fitness (mL ⁻¹ /kg ⁻¹ /min ⁻¹)	0.14	0.12	0.10	-0.24	0.27

z-WC, waist circumference z-score; HDL, high-density lipoprotein cholesterol.

^alog transformed.

Partial correlations adjusted for sex, ethnicity, total sedentary time, moderate-to-vigorous physical activity, and accelerometer wear time.

Significant associations ($p \leq 0.05$) highlighted in bold.

Sedentary patterns and cardiometabolic risk

Table 3 Multivariate-adjusted odds ratios for cardiometabolic risk factors across sedentary behaviour pattern groups for 10-14 year-old children

	Number of prolonged sedentary bouts		Duration of prolonged sedentary		Number of breaks in sedentary time		Mean duration of daily breaks in	
	per day		bouts (min/day)		per day		sedentary time (min/day)	
	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value	Odds ratio (95% CI)	P value
Abdominal obesity ¹	2.39 (0.51, 11.21)	0.27	4.07 (0.92, 18.11)	0.07	1.34 (0.26, 6.80)	0.73	0.12 (0.02, 0.87)	0.04
Hypercholesterolaemia ²	0.26 (0.02, 2.8)	0.27	0.98 (0.12, 8.11)	0.99	0.33 (0.02, 5.17)	0.43	1.06 (0.06, 17.88)	0.97
Low HDL ³	2.30 (0.47, 11.21)	0.30	0.58 (0.15, 2.21)	0.43	3.11 (0.47, 20.59)	0.24	1.51 (0.27, 8.50)	0.64
Hypertriglyceridaemia ⁴	5.25 (1.18, 23.45)	0.03	0.92 (0.26, 3.25)	0.89	1.64 (0.35, 7.75)	0.53	2.11 (0.45, 10.01)	0.35
Impaired fasting glucose ⁵	0.20 (0.03, 1.13)	0.07	1.09 (0.27, 4.43)	0.90	0.46 (0.07, 2.99)	0.41	2.71 (0.43, 16.96)	0.29
Elevated systolic BP ⁶	0.84 (0.21, 3.32)	0.80	1.55 (0.46, 5.24)	0.48	1.27 (0.29, 5.56)	0.75	0.35 (0.07, 1.86)	0.22
Elevated diastolic BP ⁶	1.01 (0.23, 4.54)	0.99	1.38 (0.36, 5.35)	0.64	0.91 (0.18, 4.54)	0.91	0.07 (0.01, 0.53)	0.01
Metabolic syndrome ⁷	3.78 (0.47, 30.40)	0.21	0.50 (0.08, 3.27)	0.47	0.57 (0.06, 5.50)	0.63	0.62 (0.06, 6.15)	0.69
Increased clustered cardiometabolic risk ⁸	4.99 (0.99, 25.10)	0.05	1.08 (0.29, 4.09)	0.91	1.10 (0.21, 5.68)	0.91	0.49 (0.09, 2.66)	0.49
Increased non-obesity clustered cardiometabolic risk ⁹	6.02 (1.29, 28.12)	0.02	0.80 (0.23, 2.86)	0.74	1.25 (0.27, 5.86)	0.78	1.70 (0.35, 8.28)	0.51
High cardiorespiratory fitness ¹⁰	1.82 (0.49, 6.74)	0.37	0.71 (0.20, 2.53)	0.60	2.09 (0.47, 9.35)	0.34	2.54 (0.58, 11.11)	0.22

CI, confidence interval; HDL, high-density lipoprotein cholesterol; BP, blood pressure.

Participants categorised into the low group were the reference comparator for each independent sedentary behaviour variable and dependent cardiometabolic risk factor.

Sedentary patterns and cardiometabolic risk

$n=55$ in the low groups for number of prolonged sedentary bouts per day, time in prolonged sedentary bouts, and number of breaks in sedentary time per day; $n=56$ in the low group for duration of breaks in sedentary time.

Model 1: adjusted for sex, ethnicity, total sedentary time, moderate-to-vigorous physical activity, and accelerometer wear time.

Model 2: adjusted for covariates in Model 1 and light physical activity.

Significant associations ($p \leq 0.05$) highlighted in bold.

¹ $\geq 90^{\text{th}}$ percentile for age and sex; ² ≥ 5.17 mmol/L; ³ ≤ 1.03 ; ⁴ ≥ 1.24 mmol/L; ⁵ ≥ 5.6 mmol/L; ⁶ $\geq 90^{\text{th}}$ percentile for age, sex and height; ⁷ ≥ 3 of the following risk factors: abdominal obesity, low HDL, hypertriglyceridemia, high systolic or diastolic BP, and impaired fasting glucose; ⁸clustered risk score ≥ 2.77 ; ⁹non-obesity clustered risk score ≥ 2.28 ; ¹⁰ > 42.1 and $37.0 \text{ mL}^{-1}/\text{kg}^{-1}/\text{min}^{-1}$ for boys and girls, respectively.